Upper Limit of Presaddle Transient Time Set by Fission Probabilities of Neighboring Isotopes

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The dynamic evolution of a fissioning system, starting from an assumed spherical shape towards the fission saddle, and eventually to the scission point, has been studied extensively. The characteristic time of this dynamic evolution, τ_D, is usually called the transient time or fission delay time. If τ_D is substantially longer than the characteristic time for particle emission, additional particles, as compared to those predicted by transition state theory, can be emitted during the transient time. This transient time effect has been advocated as an explanation for the large number of prescission neutrons, charged particles, and electric dipole γ rays, observed in relatively heavy fissioning systems. Transient times as long as $\sim 10^{-19}$ sec have been inferred from the observed prescission particles, although more recent works indicate significantly shorter transient times. However, the experimentally inferred transient times are the sum of presaddle and postsaddle delay times, since the prescission particles can be emitted either before the system reaches the fission saddle, or during the descent from saddle to scission.

The distinction between the pre- and post-saddle transient times becomes imperative when one tries to determine the effects of a transient time on the fission probabilities. A presaddle transient time necessary for the "slow" fission mode to attain its stationary rate would substantially suppress the fission probabilities, whereas postsaddle delay times do not affect the fission probabilities. Efforts have been made to separate the presaddle and postsaddle delay components from the differences in the mean kinetic energies of charged particles emitted pre- and post-saddle. However, the separation of presaddle and postsaddle particle emission is fraught with difficulties and ambiguous.

In this work, we show a new and straight-forward way to determine the upper limit of the presaddle transient time, set by the fission probabilities of neighboring isotopes. This new approach, which does not involve anything beyond the fission saddle, bypasses the difficulties associated with separating of presaddle from postsaddle particle emission.

Given a transient time τ_D, and assuming a step function for the presaddle transient time effects, the total fission probability P_f^t of the nucleus (A, Z) with excitation energy E can be written as

$$P_f^t(A,Z,E) = P_f^{1st} + P_f^{2nd} + P_f^{3rd} + \cdots, \qquad (1)$$

where

$$P_f^{1st} = P_f(A,Z,E)\, e^{-\tau_D/\tau_n},$$

$$P_f^{2nd} = P_f(A-1,Z,E-\Delta E_1) \times \left[\frac{\lambda_n}{\lambda_{CN}}\, e^{-\tau_D/\tau_n} + \frac{\lambda_n}{\lambda_n - \lambda_n'}\left(e^{-\tau_D/\tau_n'} - e^{-\tau_D/\tau_n}\right)\right].$$

In the above equation, ΔE_i is the average energy loss through the evaporation of the ith neutron; P_f is the *expected* fission probability when no transient time effects are present. λ_n, λ_{CN} are the neutron and total decay constants of nucleus (A, Z, E); λ_n' is the the neutron decay constant of the nucleus $(A-1, Z, E-\Delta E_1)$; τ_n, τ_n' denote the inverse of the corresponding decay constants. The decay constants can be calculated with the transition state theory. However, $P_f(A,Z,E)$, $P_f(A-1,Z,E-\Delta E_1)$, P_f^{3rd}, and τ_D are unknown.

While Eq. 1 looks hopelessly insoluble, it does provide clues to an upper limit of the fission delay time τ_D. When $P_f^t(A,Z,E)$ is specified, there exists a maximum value of τ_D for which Eq. 1 can be satisified. Taking the experimental value $P_f^t(A-2,Z,E-\Delta E_1-\Delta E_2)$ as the upper limit of P_f^{3rd}, and replacing P_f^{3rd} in Eq. 1 with this upper limit, and replacing $P_f(A-1,Z,E-\Delta E_1)$ with the the experimental value $P_f^t(A-1,Z,E-\Delta E_1)$, the resulting equation can then be solved for an upper limit of τ_D.

We have recently measured with high precision the fission excitation functions of the neighboring compound osmium isotopes ^{185,186,187}Os produced in ^{3}He-induced reactions on isotopically enriched tungsten targets ^{182,183,184}W, and the fission excitation functions of the neighboring compound polonium isotopes ^{209,210,211}Po produced in ^{3}He-induced reactions on isotopically enriched lead targets ^{206,207,208}Pb. The fission probabilities $P_f^t(A,Z,E)$ of different isotopes at different excitation energies can be calculated as σ_f/σ_0, where σ_0 is the fusion cross section which can be evaluated with the Bass Model.

Setting $P_f(A,Z,E) = P_f^t(A,Z,E)$, we have solved for the transient time upper limits τ_D for both the Os and the Po isotopes. The upper limit of the presaddle transient time is determined to be 1.5×10^{-20} sec for Os isotopes, and 2.5×10^{-20} sec for Po isotopes. Since this limit is quite small, most, if not all, of the transient time as determined from excess amounts of prescission particle emissions, is, therefore, postsaddle.